PHOTOELECTRIC EFFECT

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What is the Photo – electric effect?

The phenomenon of emission of electrons from metal surface exposed to light (of suitable frequency) is known as **Photo – electric effect**.

- The electrons emitted in this process known as **photoelectrons** and the current constituted by this electrons known as photoelectric current. This phenomenon also known as photoemission.

- Photo – electric effect was first experimentally verified by H. R Hertz in 1887.

- The classical wave - theory of light could not explain the **Photo – electric effect**. The failure of classical physics led Max Planck to introduce the Particle-theory (Quantum Physics) of energy. This concept stated that energy is not continuous but discrete.
Photons:

Radiant energy is quantized into localized bundles moving with velocity $c$ and having energy proportional to the frequency

$$\mathcal{E}_{ph} = h \nu$$

These particlelike bundles are called photons

In the photoelectric process one photon is completely absorbed by one electron

‘$h$’ is known as Planck Constant and $\nu$ is the frequency of the light (e. m. radiation)
Work Function (W):

In a metal electrons are bound by attraction force of nucleus. So, a certain minimum energy is required to pull out the electron from the surface of metal. It is called Work Function of the metal.

- Work function is a characteristic property of metal.
- The unit of work function is ‘eV’.
- $1 \text{ eV} = 1.6 \times 10^{-19}$

<table>
<thead>
<tr>
<th>Metal</th>
<th>Symbol</th>
<th>Work Function, eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesium</td>
<td>Cs</td>
<td>1.9</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>2.2</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>2.3</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>2.5</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>3.2</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>4.7</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>4.7</td>
</tr>
<tr>
<td>Platinum</td>
<td>Pt</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Source: Google image
Experimental Set-up to study Photo–electric effect:

'V': Potential applied between Emitter (C) and collector (A). When A is connected to (+ve) and C is (–ve), it is called Accelerating potential and reverse is known as Retarding potential.
Observations of Photo-electric Effect:

- The photoelectric current starts flowing as soon as the light supply is turned on. Actually the time lag between the shining of light and emission of electrons is less than $3 \times 10^{-9}$ second.

- The minimum frequency of light required to eject an electron from the metal surface, is called Threshold Frequency ($\nu_0$). ‘$h\nu_0$’ is the minimum energy required for electron emission therefore,

\[
W = h\nu_0
\]

The corresponding wave-length is known as cut-off wavelength ($\lambda_c$)

\[
\lambda_c = \left(\frac{c}{\nu_0}\right) = \left(\frac{hc}{W}\right)
\]

('c' is velocity of light in vacuum)

- The kinetic energy ($K$) of the photoelectrons is independent of the light intensity and only depends on the frequency of the light.
For a fixed frequency ($\nu$) of light, the numbers of emitted photoelectrons is proportional to the intensity of light. So, photo-electric current increases linearly with the intensity ($I$) of the incident light.

The photocurrent increases with accelerating potential and for some certain positive potential of collector A all the emitted electrons are collected by A. Then the current becomes maximum and known as **Saturation Current**.

Saturation current increase with the intensity ($I$) of the incident light but independent of frequency of light.
For a particular frequency of light, the photocurrent found to decrease with increase of retarding potential and for a certain value of negative potential ($V_0$) of collector, the current drops to zero. It is called **Stopping or Cut-off Potential ($V_0$)**. It is depend on the light frequency and independent of incident light intensity.

\[ eV_0 = K_{\text{max}} \]

- \( e \) = Electronic charge
- \( K_{\text{max}} \) = Maximum kinetic Energy of electron at a particular frequency
• **Laws of Photoelectric Effect:**

  • Electrons are emitted instantly.

  • Photocurrent is directly proportional to light intensity.

  • There were no photocurrent if the frequency of incident light is less than *Threshold Frequency*.

  • The maximum kinetic energy of the photoelectrons is directly proportional to the frequency (above the threshold frequency) and independent if light intensity.

  • The **Stopping Potential** is independent of light intensity and depend on frequency.
• Einstein’s Photoelectric Equation:

When light energy falls on a metal surface, then the energy of the photon is absorbed by the electron and is used in two ways:

1) One portion of energy is used to overcome the surface barrier and come out of the metal surface. This part is called ‘work function’.

2) The remaining portion of the energy is used to accelerate the photoelectron and equal to the maximum kinetic energy of the photoelectrons.

\[ K_m = E - W \]

\[ KE = h\nu - h\nu_0 \]

Source - Google image
# Comparison between Classical physics and Quantum physics about Photoelectric Effect

<table>
<thead>
<tr>
<th>Features</th>
<th>Classical Physics (Wave Theory)</th>
<th>Quantum Physics (Particle Theory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instant emission of electron</td>
<td>The transfer of energy from wave fronts of e. m. wave to electron should take a time of the order of seconds or more.</td>
<td>The energy transferred by elastic collision of photon and electron with almost no time delay.</td>
</tr>
<tr>
<td>Concept of Threshold Frequency</td>
<td>Any incident light of sufficient intensity can eject electrons.</td>
<td>To eject an electron a minimum energy is required to overcome the attraction force of nucleus. Now the energy of light is proportional to frequency and so below a minimum frequency the emission of electron can not possible.</td>
</tr>
<tr>
<td>Maximum kinetic energy of photoelectrons depend on frequency and independent of intensity</td>
<td>When the <strong>intensity</strong> of incident light wave on metal surface was <strong>higher</strong> then it posses <strong>more energy</strong> and the ejected electrons achieve higher kinetic energy.</td>
<td>The energy of photon (particle of light) <strong>only depends on frequency</strong> (E = \hbar \nu). So higher the frequency (\nu), the greater the photon energy and photoelectron get more kinetic energy (K_{\text{max}} = \hbar \nu - W).</td>
</tr>
</tbody>
</table>
Some application of Photoelectric Effect

Solar panels are nothing more than a series of metallic plates that face the Sun and exploit the photoelectric effect. The light from the Sun will liberate electrons, which can be used to heat your home, run your lights, or, in sufficient enough quantities, power everything in your home.

Source: www.futureenergy.org/picsolarpanelsmhit.jpg

The photoelectric effect will cause spacecraft exposed to sunlight to develop a positive charge.

Source: Google image

All light-sensitive detectors, including the eye and the one used in this video camera, are based on the absorption of energy from photons of light by electrons in the atoms the light falls on.
Numerical problems on Photoelectric Effect:

$\Omega 1 \quad A$ light beam of wavelength $\lambda = 4000 \text{ Å}$ falls on a metallic surface used in an experiment to study photoelectric effect. If the stopping potential is $1.5 \text{ V}$, calculate (a) the work function of the surface and (b) maximum wavelength of light that will cause the photoelectric emission.

(a) The stopping potential $V_0 = 1.5 \text{ Volt}$.
- $k_{\text{max}} = eV_0 = 1.5 \text{ eV}$

Energy of the photon: \[ E = \frac{hc}{\lambda} = \frac{1.6 \times 10^{-19} \text{ ergs}}{4000 \times 10^{-10} \text{ m}} = 4.95 \times 10^{-19} \text{ J} \]
- $E = 3.093 \text{ eV}$

Using equation 4,
\[ eV_0 = h\nu - W \]
\[ \Rightarrow W = h\nu - eV_0 = (3.093 - 1.5) \text{ eV} = 1.593 \text{ eV} \]

(b) Maximum wavelength $\rightarrow$ minimum frequency as $\lambda \propto f$.
- $\lambda_{\text{max}} = \frac{C}{\gamma_{\text{max}}} = \frac{e}{W} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.593 \times 1.6 \times 10^{-19}}$
  \[ = 7.76 \times 10^{-7} \text{ m} = 7760 \text{ Å} \]
Calculate \( \alpha \) Planck's constant and \( \beta \) the work function from the following data obtained from a photo-electric effect.

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>( \nu_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.536 Å</td>
<td>1.95 V</td>
</tr>
<tr>
<td>3.650 Å</td>
<td>0.5 V</td>
</tr>
</tbody>
</table>

From equation (1) Einstein's Photoelectric Equation,

\[
W = h\nu - e\nu_0
\]

\[
W = \frac{hc}{\lambda} - e\nu_0
\]

When \( \lambda = 2.536 \times 10^{-7} \) m, \( \nu_0 = 1.95 \) V

\[
W = \frac{hc}{2.536 \times 10^{-7}} - e \times 1.95
\]

\[
= \frac{h \times 3 \times 10^8}{2.536 \times 10^{-7}} - 1.6 \times 10^{-19} \times 1.95
\]

\[
W = 1.182 \times 10^{15} h - 3.12 \times 10^{-19} \quad (\text{I})
\]

When \( \lambda = 3.650 \times 10^{-7} \) m, \( \nu_0 = 0.5 \) V

\[
W = \frac{h \times 3 \times 10^8}{2.536 \times 3.650 \times 10^{-7}} - 1.6 \times 10^{-19} \times 0.5
\]

\[
W = 0.821 \times 10^{15} h - 0.8 \times 10^{-19} \quad (\text{II})
\]

By (I) - (II), we get

\[
W = (1.182 - 0.821) \times 10^{15} h - (3.12 - 0.8) \times 10^{-19}
\]

\[
0 = 0.361 \times 10^{15} h - 2.32 \times 10^{-19}
\]

\[
h = \frac{2.32 \times 10^{-19}}{0.361 \times 10^{15}} \approx 6.42 \times 10^{-34} \quad \text{J-sec}
\]

\[
W = (1.182 \times 10^{15} \times 6.42 \times 10^{-34} - 3.12 \times 10^{-19}) \text{ J}
\]

\[
= 4.468 \times 10^{-19} \text{ J}
\]

\[
= 2.79 \text{ eV}
\]